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# Training Conditions Influence Walking Kinematics and Self-Selected Walking Speed in Patients with Neurological Impairments

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## Abstract

Gait training is a major focus of rehabilitation for many people with neurological disorders, yet systematic reviews have failed to identify the most effective form of gait training. The main objective of this study was to compare conditions for gait training for people with acquired brain injury (ABI). Seventeen people who had sustained an ABI and were unable to walk without assistance were recruited as a sample. Each participant was exposed to seven alternative gait training conditions in a randomized order. These were: (1) therapist manual facilitation; (2) the use of a gait-assistive device; (3) unsupported treadmill walking; and (4) four variations of body weight support treadmill training (BWSTT). Quantitative gait analysis was performed and Gait Profile Scores (GPS) were generated for each participant to determine which condition most closely resembled normal walking. BWSTT without additional therapist or self-support of the upper limbs was associated with more severe gait abnormality [Wilks' lambda $= 0.20$, $F(6, 6) = 3.99$, $p = 0.047$]. With the exception of therapist facilitation, the gait training conditions that achieved the closest approximation of normal walking required self-support of the upper limbs. When participants held on to a stable handrail, self-selected gait speeds were up to three times higher than the speeds obtained for over-ground walking [Wilks' lambda $= 0.17$, $F(6, 7) = 5.85$, $p < 0.05$]. The provision of stable upper-limb support was associated with high self-selected gait speeds that were not sustained when walking over ground. BWSTT protocols may need to prioritize reduction in self-support of the upper limbs, instead of increasing treadmill speed and reducing body weight support, in order to improve training outcomes.

**Key words:** locomotor function; rehabilitation; traumatic brain injury; treadmill training

## Introduction

Gait training is a major focus of rehabilitation for many people with neurological disorders (Harris and Eng, 2004), with gait speed regarded as a good indicator of functional mobility (Schmid et al., 2007). Despite the considerable costs associated with being immobile and the large number of studies investigating the effectiveness of various gait training techniques, to date no regimen has been shown to be superior (Dickstein, 2008; Moseley et al., 2005; States et al., 2009; Wessels et al., 2010). Contemporary therapies for training gait fall into three main categories: (1) facilitation or assistance provided by a therapist, (2) gait-assistive devices, such as sticks, frames, and crutches; and (3) partial body weight support (BWS) provided by a harness suspended overhead. The most common means of providing partial BWS gait training, also known as BWS treadmill training (BWSTT), uses a harness to provide support and stability while the patient practices walking on a treadmill (Hesse, 2008).

Reduced ability to walk and reduced walking speed following neurological injury may be related to restricted opportunities to practice during rehabilitation (Bernhardt et al., 2008). Consequently, there has been much focus on BWSTT in recent years, because it provides the advantage of engaging in

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more task-specific practice (Hesse et al., 1995), a term used to describe motor training that is context-specific (Teasell et al., 2008). Task-specific practice is the optimal approach for training motor skills (Dobkin, 2004). Although included in the American Heart Association's Definitive Stroke Guidelines (Miller et al., 2010), the efficacy of BWSTT remains unclear. Seven systematic reviews have investigated the effectiveness of BWSTT for people with neurological conditions and found little benefit from this approach, as training gains have not generalized well to over-ground walking (Dickstein, 2008; Marshall et al., 2007; Mehrholz et al., 2007; Moseley et al., 2005; States et al., 2009; Swinnen et al., 2010; Wessels et al., 2010). The most recent systematic review included six BWSTT and electromechanically-assisted gait training studies in subacute stroke (Ada et al., 2010b). They reported that BWSTT (two studies) was more effective than over-ground walking in achieving independent ambulation, despite the fact that this modality has little effect on gait speed. No reasons for the failure of the enhanced training times provided by BWSTT to improve mobility outcomes have been proposed.

Randomized controlled trials investigating the effectiveness of BWSTT have usually compared outcomes to conventional gait training. Although conventional therapy may incorporate a range of strengthening, balance, and stretching exercises, conventional gait training usually involves therapist assistance or facilitation (Hesse et al., 1994, 1998; Hornby et al., 2008; Lennon, 2001; Moseley, 2005). Therapist facilitation may vary considerably between rehabilitation centers and between therapists with different levels of experience. A perceived advantage of therapist-facilitated gait training is the ability to continually adapt the assistance provided in response to the person's performance from stride to stride (Lennon, 2001). Whether or not therapist facilitation is a more effective strategy than other gait-training conditions remains unclear.

The use of assistive gait devices, such as walking frames, crutches, and canes, is common following neurological injury (Jutai et al., 2007). Although a considerable number of studies have investigated the impact of assistive devices on walking ability (Allet et al., 2009; Bacik et al., 2006; Hamzat and Kobiri, 2008; Maguire et al., 2010; Tyson, 1999; Tyson and Rogerson, 2009), to our knowledge there are no studies that have compared the training of gait with an assistive device to BWSTT or therapist facilitation. Studies comparing walking with and without the use of a gait-assistive device have found that assistive devices, contrary to popular clinical opinion, can improve the quality and symmetry of gait performance in some individuals (Kuan et al., 1999; Laufer, 2002; Tyson, 1999; Tyson and Ashburn, 1994).

Three-dimensional quantitative gait analysis (3DGA) is the current criterion standard for evaluating gait performance. It has been used to evaluate BWSTT (McCain et al., 2008; Mulroy et al., 2010; Sousa et al., 2009), therapist facilitation (Lennon, 2001), and use of an assistive device (Kuan et al., 1999) following stroke. Although these studies have investigated the impact of each intervention on gait performance, we are unaware of any study which has systematically examined each of these gait training conditions. In the absence of a superior means for training gait following neurological injury, it may be useful to identify which condition most closely approximates normal able-bodied walking. 3DGA can be utilized to compare the three contemporary conditions of gait training to determine which approach is biomechanically optimal. The condition of gait training that most closely resembles the biomechanical pattern for able-bodied human walking may be the one that is most likely to optimize mobility outcomes. It may also be the condition that should receive more resources and development, and be targeted to identify factors associated with improved transfer of training gains. Therefore, the aim of this study was to determine which condition of gait training following acquired brain injury (ABI) best promotes normal able-bodied walking.

## Methods

### *Ethics*

This project was approved by Epworth Hospital's Human Research Ethics Committee (study no. 42208), and the University of Melbourne (Ethics ID 0830540.1).

### *Participants*

Seventeen people who had sustained an ABI were recruited from the rehabilitation units at Epworth Hospital, Melbourne, Australia. The inclusion criteria were: (1) unable to walk without assistance due to ABI; (2) allowed to fully bear weight (for those who had sustained an associated lower limb fracture); and (3) willing and able to provide informed consent.

The average age of the participants was 38.7 years (SD 15.3 years, range 17–69 years). Ten of the 17 participants were male. Mean height was 175.0 cm (SD 8.6 cm), and mean body mass was 72.4 kg (SD 22.7 kg). Eleven participants had sustained extremely severe traumatic brain injuries (TBI). Extremely severe TBI is classified by a length of post-traumatic amnesia >28 days (Shores et al., 1986). The mean length of post-traumatic amnesia for this cohort was 91.6 days. Five participants had sustained a stroke and one had multiple sclerosis (MS). The length of time post-injury or diagnosis varied considerably from acute (1 month) to chronic (10 years), with a median time of 9 months.

### *Testing procedure*

A number of variations on BWSTT protocols that have been reported were included, resulting in seven gait training conditions:

1. Therapist facilitation
2. Use of a gait-assistive device
3. Treadmill training without BWS (treadmill only)
4. Treadmill training with BWS (BWSTT)
5. Treadmill training with BWS plus assistance from a therapist (BWSTT + T)
6. Treadmill training with BWS plus self-support using their own upper limbs (BWSTT + UL)
7. Treadmill training with BWS plus self-support using their own upper limbs and assistance from a therapist, i.e., conditions 5 and 6 combined (BWSTT + T + UL)

To control for the effects of practice and fatigue, the order of testing was randomized. In this study, we selected 30% BWS as the standard for each condition because it is the value most commonly reported in the literature (Hesse, 2008; Mulroy et al., 2010). Participants completed familiarization trials for each gait training condition. During each familiarization trial, the treadmill speed was increased in 0.1 m/sec increments from 0.1 m/sec until the participant identified their comfortable walking speed. Participants were blinded to the treadmill control panel so they had no knowledge of their actual gait speed. A single experienced therapist provided all of the therapist facilitation (condition 1) and/or assistance (conditions 5 and 7) to the participants.

### *Data collection*

The gait patterns for each participant were measured with 3DGA during each of the seven gait training conditions. The 3DGA was performed at the Centre for Health, Exercise and Sports Medicine, School of Physiotherapy, The University of Melbourne, using a previously described approach (Williams et al., 2010). Four additional markers were placed on a small thermoplastic plate positioned over the sacrum and secured with a firm pelvic support strap (Barrere Pelvic Strap model 384). These markers were used to track the orientation of the pelvis during all dynamic walking trials, as the harness support required for the BWSTT restricted exposure of pelvic bony landmarks such as the anterior superior iliac spines. All anatomical coordinate systems were defined per a previously described approach (Schache and Baker, 2007), except that the location of the hip joint center was predicted using the method of Harrington and associates (Harrington et al., 2007). To obtain a representative sample of each participant's gait pattern, the average of five gait cycles was calculated for each leg for each gait training condition.

### *Data analysis*

In order to compare the seven conditions for training gait, the Gait Profile Score (GPS) was selected, as evidence suggests that it is the most accurate single index of gait performance (Baker et al., 2009). Nine kinematic measures of pelvic, hip, knee, and ankle movements, together with foot progression, were collated. The mean performance of five trials for each patient's kinematic trace for each of the nine parameters was compared to the average values obtained from a sample of 10 (5 male) healthy controls (Williams et al., 2010), walking at a speed which was slow, yet adequate for community ambulation (Perry et al., 1995). The mean age of the healthy control sample was 27.3 years (range 18–35 years). The difference between the participant's performance and the mean of the healthy control sample was measured and summed into a representative GPS (Fig. 1), with higher scores representing greater abnormality. The mean GPS for the healthy controls was 1.9 (SD 0.3). The GPS for the participant's most affected side was selected and compared to determine which gait training condition was most effective at replicating normal able-bodied walking.

The GPS scores for the seven gait training conditions were compared using one-way repeated-measures analysis of variance (ANOVA). A one-way repeated-measures ANOVA was also used to compare the gait speeds across the seven conditions to investigate if the self-selected comfortable walking speed varied between conditions. An alpha level of 0.05 was set for all statistical analyses, with Bonferroni adjustment of the $p$ value performed on the *post-hoc* comparisons by multiplying the uncorrected $p$ value by the number of comparisons performed. Due to the number of pairwise comparisons performed, only significant results were reported.

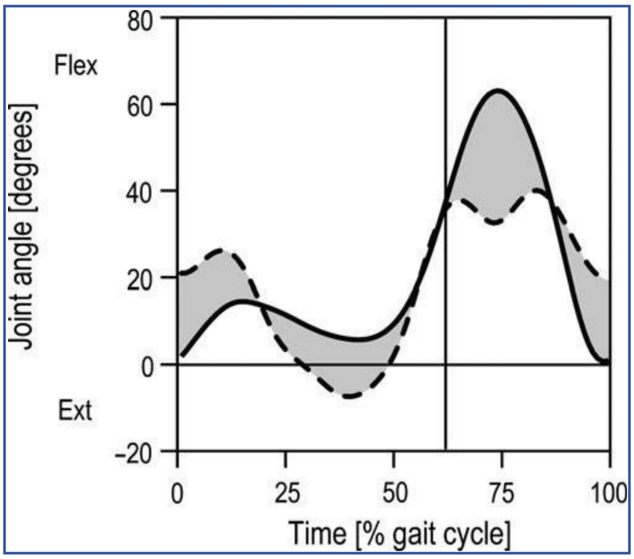

**FIG. 1.** Gait Profile Score calculation. This graph demonstrates knee joint flexion/extension during 1 complete gait cycle. The vertical line represents toe-off for the healthy controls. The solid black line represents the mean for the healthy controls. The dashed black line represents the mean of 5 trials for a study participant. The area between the lines is calculated for nine key gait parameters to determine the Gait Profile Score.

## Results

### *Participants*

Not all of the participants could satisfactorily complete each of the gait training conditions. All participants were able to perform the therapist-facilitated condition (condition 1), BWSTT + T condition (condition 5), the BWSTT + UL condition (condition 6), and the BWSTT + T + UL condition (condition 7). Four participants were unable to perform the BWSTT condition (condition 4), two participants were unable to safely walk using any type of gait-assistive device (condition 2), and two participants were unable to walk with no BWS on the treadmill (condition 3). Only five participants were responsible for the eight trials that could not be completed.

One participant used a four-wheeled gutter frame as their assistive device, six participants used a four-wheeled frame, two participants used a four-point walking stick, and six used a single forearm crutch. Nine participants also required the use of an ankle-foot orthosis ($n = 7$ left leg, $n = 2$ right leg).

### *Optimal gait training condition*

The means and standard deviations for the GPS data are presented in Table 1. The effect for gait training condition just reached significance [Wilks' lambda = 0.20, $F(6, 6) = 3.99$, $p = 0.047$, multivariate partial eta squared = 0.80]. Pairwise comparisons (with Bonferroni adjustment) showed a statistically significant difference ($p < 0.05$) between BWSTT (condition 4), and BWSTT + UL (condition 6) and BWSTT + T + UL (condition 7), indicating that the abnormality of the gait pattern significantly increased when walking with BWSTT compared to BWSTT + UL and BWSTT + T + L.

Table 1. Gait Profile Scores for Each of the Seven Gait Training Conditions

| *Gait training condition* | n | *GPS (mean)* | *GPS (SD)* | *Range* |
|---|---|---|---|---|
| 1. Therapist facilitated | 17 | 12.84 | 2.83 | 8.54–20.98 |
| 2. Gait-assistive device | 15 | 13.45 | 3.58 | 8.71–24.10 |
| 3. Treadmill only | 15 | 12.52 | 2.27 | 8.21–14.90 |
| 4. BWSTT | 13 | 15.20 | 3.94 | 8.61–22.66 |
| 5. BWSTT + T | 17 | 13.90 | 3.28 | 8.91–21.53 |
| 6. BWSTT + UL | 17 | 12.94 | 3.56 | 7.49–20.56 |
| 7. BWSTT + T + UL | 17 | 12.76 | 3.71 | 8.62–22.61 |

Higher GPS scores represent greater abnormality. The mean GPS for healthy controls was 1.9 (SD = 0.3).

GPS, Gait Profile Score; SD, standard deviation; BWSTT, body weight support treadmill training; T, therapist; UL, upper limbs.

### *Self-selected gait speeds for each of the seven gait training conditions*

The means and standard deviations for the gait speed data are presented in Table 2. There was a significant effect for gait speed [Wilks' lambda = 0.17, $F(6, 7) = 5.85$, $p < 0.05$, multivariate partial eta squared = 0.83].

When walking with therapist facilitation (condition 1), or the use of a gait-assistive device (condition 2), participants walked with significantly ($p < 0.05$) slower self-selected gait speeds. Pairwise comparisons (with Bonferroni adjustment) showed statistically significant differences ($p < 0.05$) between the two slowest conditions, walking with therapist facilitation (condition 1) and the use of an assistive device (condition 2), and treadmill only walking (condition 3), BWSTT + T (condition 5), BWSTT + UL (condition 6), and BWSTT + T + UL (condition 7).

## Discussion

Body weight support treadmill training (condition 4) was associated with greater gait abnormalities than the other gait-training conditions. Three of the four conditions with the lowest GPS scores (i.e., the least abnormal walking pattern) required participants to hold on to a stable handrail. Although these gait-training conditions resulted in comparable gait performance, they occurred at significantly higher gait speeds. For example, when walking with BWSTT + T + UL (condition 7), participants selected a speed that was three times faster than that for over-ground walking with therapist facilitation only (condition 1). The ability to maintain gait quality at significantly greater self-selected gait speeds for treadmill only (condition 3), BWSTT + UL (condition 6), and BWSTT + T + UL (condition 7), is most likely due to the addition of upper limb support. Improved gait performance may be expected for conditions for which stable upper-limb support is provided. Provision of stable support reduces the task complexity and motor control demands for walking by reducing the need to maintain balance. Even though the participants were able to support themselves with their arms when walking with the use of a gait-assistive device, the self-selected gait speeds for this condition were significantly slower. Taken together, these results suggest that to attain higher gait speeds within a session, people with ABI are dependent upon adequate upper limb support via a stable handrail. Further investigation may be warranted to explore the impact of each gait training condition on other important aspects of walking, such as lateral center of mass displacement, an indicator of postural stability (Basford et al., 2003; Chou et al., 2004; Kaufman et al., 2006).

Table 2. Self-Selected Gait Speed (m/sec) for Each of the Seven Gait Training Conditions

| *Gait training condition* | n | *Self-selected gait speed (mean)* | *SD* | *Range* |
|---|---|---|---|---|
| 1. Therapist facilitated | 17 | 0.30 | .21 | 0.10–0.80 |
| 2. Gait-assistive device | 15 | 0.31 | .23 | 0.10–0.70 |
| 3. Treadmill only | 15 | 0.76 | .37 | 0.20–1.40 |
| 4. BWSTT | 13 | 0.56 | .43 | 0.20–1.80 |
| 5. BWSTT + T | 17 | 0.68 | .48 | 0.20–1.90 |
| 6. BWSTT + UL | 17 | 0.84 | .53 | 0.20–2.10 |
| 7. BWSTT + T + UL | 17 | 0.90 | .53 | 0.20–2.40 |

GPS, Gait Profile Score; SD, standard deviation; BWSTT, body weight support treadmill training; T, therapist; UL, upper limbs.

A recurrent finding of systematic reviews investigating the effectiveness of BWSTT is that it is not significantly better than conventional therapy in terms of functional outcome (Dickstein, 2008; Moseley et al., 2005; States et al., 2009; Wessels et al., 2010). Possible reasons for this may include BWSTT protocols using treadmill speeds that are unsustainable without stable upper limb support. Most BWSTT studies have allowed participants to self-support with their upper limbs. Although BWSTT would appear to have high task-specificity for the goal of improving mobility, training protocols that have primarily focused on increasing treadmill speed (Ada et al., 2010a; da Cunha et al., 2002; Franceschini et al., 2009; Peurala et al., 2009), and reducing BWS (Ada et al., 2010a; da Cunha et al., 2002; Franceschini et al., 2009; Peurala et al., 2009; Pohl et al., 2007; Visintin et al., 1998), may have inadvertently failed to consider the impact of stable upper limb support. The results obtained in this study indicate that if people with ABI utilize upper limb support during BWSTT, they are most likely to be walking at a speed three times faster than that which can be obtained with therapist facilitation or the use of a gait-assistive device. When required to cease upper limb support, four participants were unable to perform BWSTT (condition 4), and those who could walked at significantly reduced self-selected speeds. Self-selected gait speed is a strong predictor of functional mobility (Perry et al., 1995), so it is intuitive to prioritize gait speed as a goal of any BWSTT protocol (Ada et al., 2010a; da Cunha et al., 2002; Franceschini et al., 2009; Peurala et al., 2009). Yet these results indicate that cessation of upper limb support may require greater prioritization in BWSTT protocols, because participants may be inadvertently self-selecting high gait speeds, which may not generalize to functional over-ground walking, thus negating training gains.

Stable support during walking does not exist, as even the most supportive walking frames have to be self-propelled and may tip if used incorrectly. It may therefore be warranted, if considering BWSTT, to implement a training protocol that prioritizes cessation of upper limb support as a criterion for training progression. Two small studies using BWSTT in stroke have reported protocols that required participants to cease handrail support prior to increasing treadmill speed (McCain et al., 2008; Mulroy et al., 2010). The results of these two studies, although the samples were small, indicate that positive outcomes are associated with prioritizing reduction in upper limb support when using BWSTT.

Higher treadmill speeds may also inadvertently impact training volumes. Although randomized controlled trials usually ensure equivalent training time for BWSTT and conventional gait training, higher treadmill speeds provide greater whole-task training compared to over-ground training (Ada et al., 2010b). However, several studies have reported greater distance walked or greater number of steps taken with BWS when compared to over-ground gait training (Ada et al., 2010a; Pohl et al., 2007; Tong et al., 2006). It is possible that subjects participating in BWSTT trials are, in effect, achieving higher levels of task-specific practice with BWSTT compared to conventional over-ground walking, even with equivalent training time.

### *Limitations*

The number of participants was low, so care must be taken when interpreting the results. This study focused only on people who required assistance to walk, so no conclusions can be drawn regarding the impact of the gait training conditions evaluated in those who have neurologically-based gait disorders, yet are able to walk unaided. Further, this study does not provide any indication as to which condition of gait training may be most effective; it simply provides a guide regarding the extent to which each condition was able to achieve a normal able-bodied walking gait pattern.

The clinical presentation of the participants in this study varied considerably, reflecting the range of patients receiving therapy in a neurological rehabilitation unit. It may be possible that different conditions for training gait are optimal for patients with differing neurological conditions, such as TBI, stroke, or MS. Further, the clinical presentation of TBI or stroke may also vary considerably. Although the sample was quite heterogeneous in terms of clinical presentation, we are unaware of any evidence that suggests that different conditions for training gait should be favored for different clinical presentations. Similarly, the age range for participants in this study also varied considerably, yet normative gait speeds varied little across the spectrum sampled in this cohort, so age is unlikely to have impacted our results (Nigg et al., 1994). Although factors such as age, neurological condition, or clinical presentation, may impact the effectiveness of gait-training conditions, we are unaware of any evidence favoring selection of one condition over another based on any of these potentially confounding factors.

## Conclusions

When training walking to people with ABI, the gait-training conditions that best resembled normal able-bodied walking required self-support of the upper limbs, with the exception of therapist facilitation. Conditions that provided self-support of the upper limbs also resulted in higher self-selected gait speeds. BWSTT without therapist assistance or self-support of the upper limbs was associated with significant deterioration in gait performance. This finding suggests that patients who are participating in BWSTT may be inadvertently practicing at high self-selected gait speeds that are not sustained when walking over ground. Protocols for BWSTT may need to prioritize reduction in self-support of the upper-limbs, rather than increasing treadmill speed and reducing BWS, in order to transfer training gains to over-ground walking and improve rehabilitation outcomes.

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## Author Disclosure Statement

No competing financial interests exist.

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